Building Research Establishment Digest

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Assessment of damage in low-rise buildings

with particular reference to progressive foundation movement

This digest discusses the assessment and classification of visible damage resulting from structural distortion. The assessment is based on a description of work considered necessary to repair the building fabric; classification into six categories is recommended, taking into account the nature, location and type of damage. The various causes of ground movement giving rise to damage are described briefly and emphasis is given to the identification of conditions where the movement might lead to progressive deterioration.

The most common causes of damage are discussed. It is concluded that for damage of Category 2 or less cracking may result from a combination of causes which are difficult to identify and the cost and effort involved in carrying out an identification would be disproportionate to the scale of the damage, except for circumstances where the movement is likely to be progressive. It is rare for damage to progress beyond Category 2 and when it does ground movement is usually the cause.

The digest will assist building professionals, property valuers and insurance advisors both in putting building damage into its true perspective and in determining necessary action, either in the form of seeking expert advice or in recommending simple repairs.

The severe drought of 1975/76 brought to the public's attention the fact that houses and other low-rise buildings are susceptible to cracking of the materials from which the buildings are constructed. That widespread publicity and some alarm were generated reflects not so much the severity of the damage as the general ignorance both of causes of damage and the amounts which masonry structures can tolerate. It is important to realise that very few buildings, if any, exist without some form of damage. How much of this will be tolerated depends on a number of factors including the type of building, the function it is to perform, the location and nature of the damage, the expectations of the user and the cost of repair work in relation to the value of the building. Many of the ways in which cracking can be produced in buildings are discussed in Digests 75, 176 and 200.

One of the many causes of damage is foundation movement resulting especially from the drying shrinkage of clay subsoil. Damage from this cause is not a new phenomenon and has been experienced many times in the past. However, the 1975/76 drought, whilst admittedly being more extensive than previous dry spells, initiated a spate of damage claims on insurance companies out of all proportion to its severity. Indeed, cases of damage, whilst being geographically more widespread, were no more severe than have been identified by the Building Research Establishment in previous dry spells, such as the dry summers of 1946 and 1947. The growth in claims for subsidence damage is shown in the table below, which was produced from figures supplied by leading household insurers.

Annual number of claims notified to 15 major insurance offices, 1971–1979

1971	164
1972	509
1973	817
1974	1,705
1975	3,821
1976	20,922
1977	11,251
1978	7,795
1979	7,454

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Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

In the two-year period following the end of the drought in August 1976, 90 properties were examined which suffered damage during and soon after the drought. These were cases specifically brought to the attention of BRE, largely by professionals and probably they represent the worse end of the spectrum of subsidence damage. In addition, case records supplied by NHBC (20) and major household insurers (30) were examined. The 'worst' examples were requested. The overall sample size was, therefore, 140.

Examining the results of this survey it was apparent that one single factor had been responsible for the massive increase in damage claims: when house insurance cover had been enhanced in 1971 by insurance companies to idemnify against damage caused by ground subsidence, no qualifications had been placed on the amount of damage occurring. In consequence, many cases of damage hitherto regarded as of no great importance had become the subject of insurance claims. In addition, houses with cracks which would once have been disregarded were being significantly devalued unless expensive remedial measures were carried out.

It also became apparent that extensions to existing buildings and structural protrusions such as bay windows and porches were especially vulnerable to slight cracking where they joined the main structure. As will be discussed later, damage to extensions, usually ascribed to clay shrinkage, may well result from other causes.

The oversensitivity of the housing market has also affected new construction. Local authority building inspectors are now much more cautious and it is evident that unnecessarily large amounts of money are being spent on new foundations for no apparent reason other than in an attempt to prevent small cracks which, when they occur, may be totally unconnected with foundation movement. It is known, for example, that 3 m deep trench foundations have been used in a number of locations and even 5 m deep trench foundations have been reported for clay soils where 1 m deep trench foundations would have been regarded as adequate in the past.

During the course of the investigations it was concluded that inadequate attention was paid to describing building damage and that the essential first step in any assessment should be to ensure that all visible damage is properly recorded and classified in terms of an objective, widely accepted scale. The main purpose of this digest is to discuss the recording and classification of damage to enable rational decisions to be made on such questions as severity of damage, its cause and appropriate remedial measures.

Reporting damage

The reporting of damage is frequently less than satisfactory for assessing the severity and cause of damage. Statements like 'extensive cracking to interior walls' are often the only description of damage given for a property. Furthermore, the subjective judgement of individuals on the seriousness of damage varies considerably, so that properties with similar levels of damage brought about by similar events may undergo vastly different degrees of remedial work.

A prerequisite for the objective classification of damage in a building is a thorough, well-documented survey. A suggested procedure for carrying out such a survey consists of:

On a sketch of each damaged wall, draw the position and direction of any cracks. Distinguish where possible between tensile cracks, compressive cracks (indicated by small flakes of brick squeezed from the surface and by localised crushing) and shear cracks (indicated by relative movement along a crack of points on opposite sides of it). Note the direction of any crack taper, crack widths, and the frequency of cracks if they are too numerous to record individually. If both external and internal crack patterns are plotted (as full and broken lines respectively) on the same elevation drawings, the mode of distortion and cause of movement can be better understood. An example of such a plot is shown in Fig 1. Generally, cracks produced by foundation movement are not widely distributed throughout a building, but tend to be concentrated in areas where maximum structural distortion and structural weak points coincide. In these areas, cracks are usually few in number so that

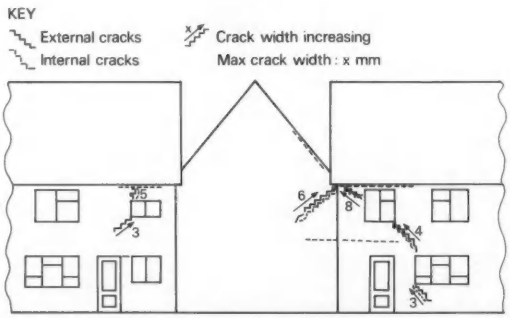

Fig 1 Crack plotting on building elevation

the recording of crack density is not onerous. Photographs provide a useful record of crack patterns and density; Figures 2 and 3 are typical cases. Any movement one side of a crack in relation to the other in a direction out of the plane of the wall will also help to identify the mode of distortion.

Fig 2 Category 2 subsidence damage – studs are used to monitor crack width

Fig 3 Category 3 damage – movements predominantly rotational and horizontal

Try to determine the approximate age of the cracks; this can be done by questioning the occupants on the date of discovery and by examining the fracture surfaces, particularly of external cracks, for signs of age. For instance, recent cracks in brickwork have a clean appearance, whereas older cracks show signs of dirt accumulation.

Where possible, measure or estimate the magnitude of any distortion and movement of the building, eg tilt and bulge of walls, slope of floors and slip on damp proof course. The plotting of such values on a drawing of the building can be very helpful; Figure 4 shows a plot of the results of plumbing of walls. A series of level readings on a course of brickwork near ground level can provide an indication of both the direction of vertical movement and the part of the structure where it is concentrated. Figure 5 shows an example of a plot

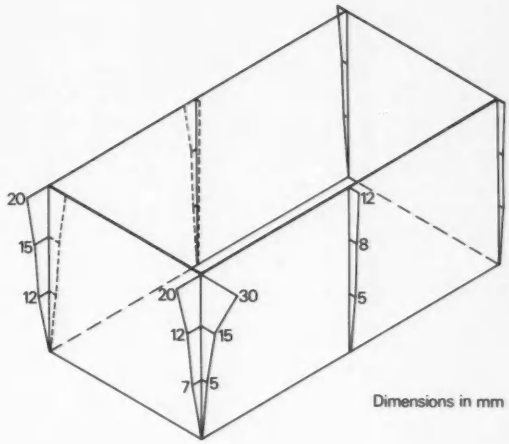

Fig 4 Verticality plot for a pair of semi-detached houses

of relative levels around a building. Of course, care is necessary in interpreting such measurements as the brick courses may not have been horizontal at the time of construction. Ideally, a series of measurements at different dates should be taken to show if movements are continuing. While this will not usually be practical for full surveys of level and verticality, it may be possible to obtain a series of measurements

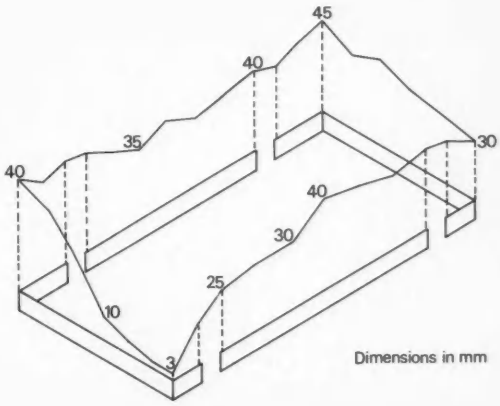

Fig 5 Level plot for a pair of semi-detached houses

with time of the widths of cracks. Many cases of alleged subsidence damage take considerable time to be resolved so that such a series of measurements, over say six months to a year, may well be practicable and of immense value in determining cause. Evidence of building distortion is often hidden in lofts; the ends of roof joists and purlins should be examined to establish the extent of any movement. Movement in roofs can also be detected by observing gaps between tiles.

Describe how the serviceability of the building has been impaired, eg doors and windows jamming, window panes cracked, draughts and rainwater penetrating cracks, and service pipes fractured.

Give a thorough description of the materials of walls and finishes and their condition, especially that of the mortar. Information of this type can often enable the identification of causes other than ground movement, for example shrinkage of concrete products, or differential thermal expansion of dissimilar materials, as well as assisting in the selection of suitable methods of structural repair.

Record details of the construction because this can have a very significant effect both on degree and location of structural cracking. Every effort should be made to establish basic information about the structure, for example whether it has solid or cavity walls and the way in which the floor has been constructed. Whether or not the floor slab has been carried off the inner leaf, for example, or is floating (see Fig 6) can significantly affect the response of the structure to foundation movement, the way in which damage may occur and the form of remedial works.

Where the cause of damage is believed to be foundation movement, additional factors may need to be considered, depending on the scale of the damage sustained. It may be necessary to carry out a thorough examination of the foundations in the area of most movement and also to determine the nature of the underlying ground (see *Assessing the possibility of severe damage due to progressive ground movement).* In both these cases it may be necessary to call for the services of a suitably qualified civil or structural engineer.

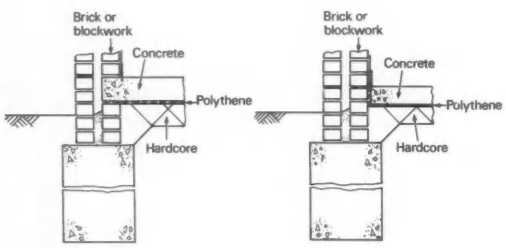

Fig 6 Alternative forms of floor construction

Classification of damage

Three broad categories of damage should initially be considered: 'aesthetic', 'serviceability' and 'stability'. The first comprises damage which affects only the appearance of the property. The second includes cracking and distortion which impair the weathertightness or other function of the wall (eg sound insulation of a party wall may be degraded), fracturing of service pipes and jamming of doors and windows. In the third category are cases where there is an unacceptable risk that some part of the structure will collapse unless preventative action is taken. Very often when damage is described no distinction is made between these three categories, making it impossible to gauge the severity of the problem.

It is only a short step from the three, general descriptions of damage to the more detailed classification proposed[1] and shown in Table 1; this defines six categories of damage, numbered 0 to 5 in increasing severity.

The classification is based on the ease of repair of visible damage to the building fabric and structure and has been derived from a number of previous studies [2, 3, 4, 5]. Thus, in order to classify visible damage it is necessary when carrying out the survey to assess what type of work would be required to repair the damage both externally and internally. The following points should be noted:

The classification relates only to visible damage at a given time and not its cause or possible progression which should be considered separately.

In Table 1 the category of damage (0 to 5), which is an objective statement, has been separated from the more subjective statement of the degree of damage. It is recognised that the 'degree' of damage can vary, for example between 'slight' or 'moderate', depending largely on the opinion of the assessor, as well as on the function of the building, the location of the damage and other factors; the aim in introducing 'category of damage' is to make the assessment more independent of personal opinion.

Great care must be taken to ensure that the classification of damage is not based solely on crack width since this factor alone can produce a misleading concept of the true scale of the damage. It is the ease of repair of the damage which is the key factor in determining the overall category of damage for the whole building.

It must be emphasised that Table 1 relates to visible damage and more stringent criteria may be necessary where damage may lead to corrosion, penetration or leakage of harmful liquids and gases or structural failure.

For most cases, categories 0, 1 and 2 can be taken to represent 'aesthetic' damage, Categories 3 and 4 'serviceability' damage and Category 5 'stability' damage. However, these relationships will not always exist since localised effects, such as the instability of an arch over a doorway, may influence the categorisation. Judgement is always required in ascribing an appropriate category to a given situation.

Table 1 Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry

Category of damage	Degree[1] of damage	Description of typical damage *Ease of repair in italic type*	Approximate crack width *mm*
0	Negligible	Hairline cracks of less than about 0.1 mm width are classed as negligible	Up to 0·1[2]
1	Very slight	*Fine cracks which can easily be treated during normal decoration.* Perhaps isolated slight fracturing in building. Cracks rarely visible in external brickwork.	Up to 1[2]
2	Slight	*Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings.* Cracks not necessarily visible externally; *some external repointing may be required to ensure weathertightness.* Doors and windows may stick slightly.	Up to 5[2]
3	Moderate	*The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.* Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5 to 15[2] (or a number of cracks up to 3)
4	Severe	*Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows.* Window and door frames distorted, floor slopes noticeably[3]. Walls leaning[3] or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15 to 25[2] but also depends on number of cracks
5	Very severe	*This requires a major repair job involving partial or complete re-building.* Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	usually greater than 25[2] but depends on number of cracks

Notes: 1 It must be emphasised that in assessing the degree of damage account must be taken of the location in the building or structure where it occurs, and also of the function of the building or structure.
2 Crack width is one factor in assessing category of damage and should not be used on its own as direct measure of it.
3 Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.

Causes of damage

So far, only the reporting of damage and its classification have been discussed. However, it is the cause of the damage and whether it will be progressive that is of great concern. There are many causes of building damage brought about by differential movements. Broadly, they can be divided into those associated with the structure itself, and those associated with the ground beneath the structure.

Causes associated with the structure include such items as material shrinkage and creep, corrosion or decay, differential thermal movements in dissimilar materials and poor detail design or workmanship. It is rare for damage due to such causes to exceed or to deteriorate beyond Category 2 in Table 1, except perhaps very locally in a building.

Causes associated with the ground include ground subsidence and heave due to volume changes in clay soils, settlement and heave of floor slabs on unsuitable or poorly-compacted in-fill beneath the slab, instability of sloping ground, movement due to consolidation of poor ground or made-ground, mining subsidence, movement caused by nearby excavations or chemical attack on foundation concrete. Also included is differential settlement induced by unequal foundation pressures arising from such factors as extensions added to existing buildings or concentrations of load, for example under chimneys. Damage from these causes can fall within any of the categories described in Table 1.

Thus Category 2 damage can result from a variety of causes which are frequently very difficult to identify. Indeed, at this level damage may result from a combination of the above factors. If damage exceeds Category 2 it is often much easier to identify the cause (which is frequently associated with ground movement) and hence prescribe a suitable remedy.

Category 2 defines the stage above which repair work requires the services of a builder. For domestic dwellings, which constitute the majority of cases, damage at or below Category 2 does not normally justify remedial work other than the restoration of the appearance of the building. For the cause of damage at this level to be accurately identified it may be necessary to conduct detailed examinations of the structure, its materials, the foundations and the local ground conditions. Consequently, unless there are clear indications that damage is progressing to a higher level it may be expensive and inappropriate to carry out extensive work for what amounts to aesthetic damage. Cases of progressive damage are rare and since they are mainly associated with ground movement a brief discussion of the factors involved follows. It should, however, be emphasised that it is a highly specialised topic usually requiring the advice of an expert structural or civil engineer. The aim of this discussion is to give advice on when to call in such an expert.

Assessing the possibility of severe damage due to progressive ground movement

Two questions frequently confront those examining a damaged property: is the damage due to foundation movement, and will it get progressively worse?

Damage due to foundation movement

It is essential to carry out a thorough survey, as described in *Reporting damage,* from which records of damage and distortion should be seen to be reasonably consistent with foundation movement. The following observations would indicate such movement:

Cracks usually show externally and internally and may extend through the dpc and down into the foundation, though this is unlikely for Category 2 damage or less;

Crack tapers should be consistent with differential foundation movement; see, for example, Figure 7;

Crack patterns should be reasonably consistent with observed or measured distortions (see *Reporting damage* and Fig 7);

Floors slope, walls tilt, window and door openings distort producing uneven clearance and jamming.

Thus the survey summarised in Figs 1, 4 and 5 points to foundation settlement at the near corner of the building.

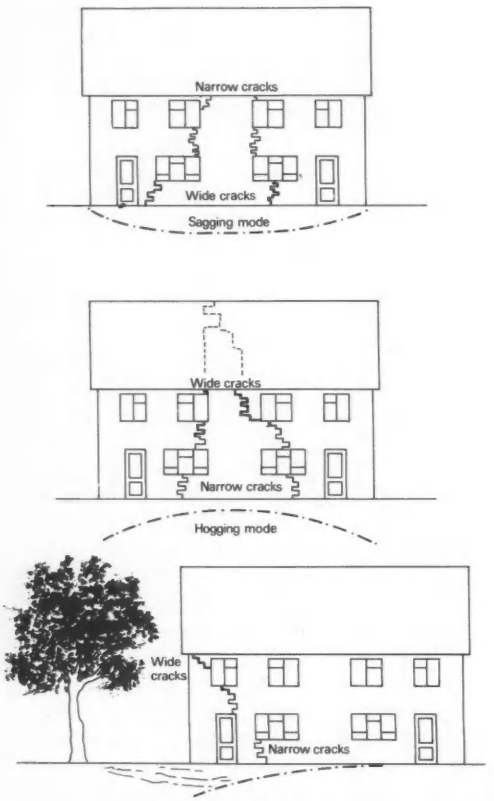

Fig 7 Crack patterns associated with different modes of distortion

Progressive movement

If the damage is reasonably consistent with foundation movement it is then necessary to assess the likelihood of it becoming progressively worse. The main causes of foundation movement are listed in *Causes of damage;* some comments on the more common ones are:

Clay soils A major factor discussed in detail in *Shrinkage and heave due to clay soils.*

Floor slab movement (See Table 2) This is a common cause of damage and results from inappropriate or poorly compacted under-floor fill. Damage is generally confined to the slab and the junctions between it and external walls and also to internal partitions carried on the slab. The problem usually manifests itself early in the life of the building although it may not be discovered at the time it occurs and if not serious at this stage it is unlikely to give rise to long term progressive deterioration.

Chemical attack Attack by sulphates (Digest 250) or acid substances in the natural ground is rarely, if ever, sufficiently destructive to cause significant damage to the shallow foundations of low-rise buildings since these are usually sited above ground water level. However, attack by aggressive chemical compounds in fill material (Digest 222) has resulted in numerous cases of disintegration and expansion of ground bearing slabs and foundation brickwork, particularly where burnt colliery shale has been used as underfloor filling.

How far any damage will progress depends on the depth and nature of the fill material.

Instability of sloping ground Ground movement due to slope instability usually results in cracking of roads, garden walls, services, etc as well as the building itself. If progressive movement of sloping ground is thought to be the cause of damage the advice of a suitably qualified civil or structural engineer should be obtained.

Consolidation of poor ground or made ground This problem usually manifests itself within the first 10 years of the life of the building, in the form of progressive damage. If it is suspected as the cause of the damage the advice of an expert structural or civil engineer should be obtained. It is helpful to assemble all readily obtainable information about the history of the site such as the geological map and current and old Ordnance Survey maps. Aerial photographs are particularly valuable in revealing previous uses of the site. Local residents can often provide useful historical information about past activities on or near the site. These sources of information are easily obtainable and can be extremely valuable in assessing whether the site has been in-filled or whether soft marshy conditions prevailed earlier. If the available evidence points to a risk of progressive settlements it will usually be necessary to carry out a ground exploration with trial pits and/or borings located in the areas of greatest movement.

Mining subsidence In districts where mining subsidence is anticipated it is advisable to seek the help of the National Coal Board and other experts in mining subsidence.

Lowering of the water table by the action of brine pumping can also cause ground subsidence.

Table 2 Classification of visible damage caused by ground floor slab settlement

The classification below attempts to quantify the assessment of floor slab settlement damage in a similar way to that for superstructure damage, given in Table 1. It has not yet been used extensively to determine its applicability. It should be noted that the categorisation may be qualified by the possibility of progression to a higher category; this should arise only when examination has revealed the presence of voids or areas of loosely compacted fill (or degradable material) beneath the floor slab such that more settlement can be expected.

Category of damage	Degree of damage	Description of typical damage	Approximate (a) crack width (b) 'gap' (1) *mm*
0	Negligible	Hairline cracks between floor & skirtings	(a) NA (b) up to 1
1	Very slight	Settlement of the floor slab, either at a corner or along a short wall, or possibly uniformly, such that a gap opens up below skirting boards which can be masked by resetting skirting boards. No cracks in walls. No cracks in floor slab, although there may be negligible cracks in floor screed and finish. Slab reasonably level.	(a) NA (b) up to 6
2	Slight	Larger gaps below skirting boards, some obvious but limited local settlement leading to slight slope of floor slab; gaps can be masked by resetting skirting boards and some local rescreeding may be necessary. Fine cracks appear in internal partition walls which need some redecoration; slight distortion in door frames so some 'jamming' may occur necessitating adjustment of doors. No cracks in floor slab although there may be very slight cracks in floor screed and finish. Slab reasonably level.	(a) up to 1 (b) up to 13
3	Moderate	Significant gaps below skirting boards with areas of floor, especially at corners or ends, where local settlements may have caused slight cracking of floor slab. Sloping of floor in these areas is clearly visible. (Slope approximately 1 in 150) Some disruption to drain, plumbing or heating pipes may occur. Damage to internal walls is more widespread with some crack filling or replastering of partitions being necessary. Doors may have to be refitted. Inspection reveals some voids below slab with poor or loosely compacted fill.	(a) up to 5 (b) up to 19
4	Severe	Large, localised gaps below skirting boards: possibly some cracks in floor slab with sharp fall to edge of slab; (slope approximately 1 in 100 or more). Inspection reveals voids exceeding 50 mm below slab and/or poor or loose fill likely to settle further. Local breaking-out, part refilling and relaying of floor slab or grouting of fill may be necessary; damage to internal partitions may require replacement of some bricks or blocks or relining of stud partitions.	(a) 5 to 15 but may also depend on number of cracks (b) up to 25
5	Very severe	Either very large, overall floor settlement with large movement of walls and damage at junctions extending up into 1st floor area, with possible damage to exterior walls, or large differential settlements across floor slab. Voids exceeding 75 mm below slab and/or very poor or very loose fill likely to settle further. Risk of instability. Most or all of floor slab requires breaking out and relaying or grouting of fill; internal partitions need replacement.	(a) Usually greater than 15 but depends on number of cracks (b) greater than 25

Note 1 'Gap' refers to the space – usually between the skirting and finished floor – caused by settlement after making appropriate allowance for discrepancy in building, shrinkage, normal bedding down and the like.

Shrinkage and heave due to clay soils *(Digests 240, 241 and 242)* This is the major cause of damage due to foundation movement, but in the majority of cases the damage is only of Category 2 magnitude or less. (Of the 140 cases described earlier, about 70 per cent fell within Category 2 or less.) If clay subsoil is suspected of being the cause of damage the following three distinct situations must be recognised: (1) open ground away from major vegetation; (2) buildings near existing trees and (3) buildings on sites newly cleared of trees. In all these situations the following investigations are required:

Record the damage
Establish that it is consistent with foundation movements
Investigate the subsoil by means of trial pits which must reveal the depth of foundations, the presence of clay and, in the case of (2) and (3) above, the presence of fine roots below the foundations;
Ascertain the history of the site (including previous vegetation), building and dates of observed movement and damage;
Record the position, species and approximate age of all nearby trees and shrubs;
Record the position and condition of nearby drains.

Open ground For foundations less than about 1 m deep in clay soils seasonal foundation movements take place which may give rise to slight cracks which open and close seasonally. Though sometimes unsightly, these cracks are easily masked.

Buildings near existing trees[6] Where the action of existing trees has been identified as the principal cause of foundation subsidence care and experience are required in assessing the likelihood of progressive movement and hence in planning remedial action. The following factors should be noted:

Where the trees have reached or are close to maturity, although seasonal shrinkage and swelling movements can be anticipated, larger movements are only likely to occur in exceptional spells of dry weather. Felling of such trees can lead to worse damage due to swelling of the clay. Tree pruning may offer an acceptable way of reducing the tree influence.

If the trees are still far from mature there is a possibility that progressive foundation movement will take place giving rise to increasingly severe damage. Specialised advice on remedial action should be obtained and it may be necessary to consider pruning or felling the trees that are positively identified as the cause of movement.

Small alterations in the environmental conditions such as the repair of a leaking drain can lead to further root growth and the possible effects should be considered.

For buildings damaged by shrinkage of clay the likelihood of recurrence of damage (not necessarily progressive) in very dry weather may depend on whether or not structural damage extends down into the foundations. If a foundation is completely fractured then a hinge can develop at the point of fracture which may produce recurrence of structural damage in the future. However, such a foundation fracture is unlikely to occur for damage of Category 2 or less.

Buildings on sites recently cleared of trees When trees and shrubs are removed from a shrinkable clay site any deep zone of desiccated clay induced by the roots will tend to absorb moisture and the ground will swell. Sometimes the swelling may continue for many years. If damage is consistent with foundation movement, there is a risk of progressive movement if there is evidence of previous large vegetation on the site and trial pits reveal desiccated clay with fine roots beneath the foundation; specialist advice from a structural or civil engineer should be obtained.

Despite the qualifications mentioned above, in the light of long experience at BRE prior to the 1975/76 drought and the examination of the 140 cases arising from the drought it can be said that progressive subsidence damage is most uncommon. Only seven of the cases were regarded as involving progression extending beyond the duration of the drought and of these, three or four involved tree removal which has been clearly identified as a situation where progression can occur. Consequently, any precipitate action by interested parties on a case of subsidence damage due to clay shrinkage, whether this action be in the form of removal of suspect trees or underpinning of the affected area of the structure, would be unwise for levels of damage of no more than Category 2. The only certain way of confirming the progression of damage is to take a series of measurements with time.

Acknowledgement
The Building Research Establishment is grateful to Professor J B Burland, Imperial College of Science and Technology, for his valuable contribution to this digest.

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BRE Digests

75 Cracking in buildings
176 Failure patterns and implications
200 Repairing brickwork
222 Fill and hardcore
240 Low-rise buildings on shrinkable clay soils: Part 1
241 Low-rise buildings on shrinkable clay soils: Part 2
242 Low-rise buildings on shrinkable clay soils: Part 3
250 Concrete in sulphate-bearing soils and groundwaters

Correction to Digest 248:
The drawings of figs 1 and 2 have been inadvertantly transposed

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